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Children's ideas about ecology 1: theoretical background, design and methodology

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Children's ideas about ecology 1: theoretical background, design and methodology

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This paper provides an introduction to a study of the ecological understandings of children aged 5–16 years in schools in the north of England. Children's ideas about selected ecological concepts were elicited through a series of written tasks and individual interviews set in a range of contexts, referred to here as probes. Responses of about 200 pupils, across the age range, were obtained on each probe. In this paper, issues relating to theoretical background, design and methodology are outlined. Two further papers present the major findings of the study: the first reports children's ideas about the cycling of matter between organisms and between organisms and the abiotic environment (Leach *et al.* in press a); the second reports children's ideas about the interdependency of organisms in ecosystems (Leach *et al.* in press b).

Background to the study

In 1989 the National Curriculum Council commissioned the Children's Learning in Science Research Group to carry out a research project to document, across the 5–16 age range, the development of children's conceptual understandings in science in order to inform revisions to the newly introduced National Curriculum. Some attention had already been given, in the UK research literature, to conceptual progression in the physical sciences across the 5–16 age range (e.g. Baxter 1989, Brook *et al.* 1989, Holding 1987) and it was thought that a study in the biological domain was necessary to provide a balanced research perspective in order to inform curriculum planning.

Although several studies have investigated children's understanding of photosynthesis at specific ages (reviewed by Wood-Robinson 1991), little work has been done to explore learners' understandings of matter cycling and energy flow. The present study was therefore designed to examine the ways in which children of different ages think about and explain situations which involve cycles of matter, flows of energy and the interdependency of organisms in ecosystems.The purpose of this introductory paper is to explain the rationale for the methodology used in the study, to outline how it was developed and to describe the tools used to probe children's understanding. Further papers will describe the findings from the study.

Theoretical background

A fundamental issue for any study which sets out to monitor children's thinking in specific concept areas relates to the nature of the data which are collected. What, for example, are the assumptions being made about the status of the children's ideas

which are collected and reviewed during the study? When reference is made to general trends in progression in children's thinking how is progression in reasoning conceptualized? These are basic questions which have significance for both the research methodology and interpretation of data. The present study describes progression in thinking about natural phenomena in terms of three interrelated factors: students' knowledge of phenomena; the ontological commitments associated with that knowledge; and students' epistemological commitments.

Progression in learning is not only associated with students' knowledge of phenomena. It is often associated with changes in children's basic assumptions about the nature of the world, i.e., in their ontologies. Such ontological changes include, for example, moving from the idea that 'air is nothing' to believing that 'air is a substantive medium'; or coming to see that 'matter is conserved' rather than 'matter is used up'. Each of these examples represent shifts in students' fundamental assumptions about the nature of the world. In addition to developments in ontological commitments, learning science also involves changes in the assumptions children make about the nature of scientific knowledge: it involves epistemological changes. This becomes apparent when reviewing the nature of children's explanations at different ages. Young children, for example, tend to offer descriptions of phenomena rather than explanations: 'Why does the apple go rotten?' 'Because it is brown and soft'. As children get older they are more likely to use causal explanations. Other epistemological changes may relate to the extent to which ideas are internally consistent or generalizable across a range of phenomena. The point which is being made here is that mapping progress in children's thinking with regard to particular phenomena involves more than just reporting the ideas and concepts used: progression is also characterized by developments in other aspects of children's reasoning.

A further issue for consideration relates to the question of what might prompt development in children's thinking. It is proposed that children's thinking about particular phenomena is influenced both by social factors (principally through language) and by experience with phenomena.

Social influences include everyday ways of talking about, and referring to, the phenomena under consideration. These everyday ways of knowing or 'life world knowledge' (Solomon 1987), are often taken for granted by both children and adults alike. They are views which are part of a common culture and as such they may, or may not, be in accord with the science perspective. One example of such an everyday way of knowing would be the notion that 'plants feed from the soil'. This is an idea which is counter to the science point of view, which is unsupported by any direct form of evidence (although there may be circumstantial evidence such as the use 'plant foods' which are added to the soil), and yet is firmly established as part of common knowledge. As social beings, children are enculturated into many such ways of knowing.

At the same time, experience of the natural world is likely to influence children's thinking, especially with regard to ecological phenomena. Children see for themselves nesting birds, grazing cattle, decaying fruit and the like and these experiences are likely to affect their thinking and expectations about natural phenomena. Nevertheless, it is important to recognize that such 'experience' is always mediated by current social representations and as such it is difficult, in practice, to disentangle experiential and social influences.

Suffice it to say that when children are introduced, in school or elsewhere, to the

science view of the concepts and phenomena which are of interest in this study, they start with an established personal history of listening, talking, experiencing and thinking about the matters under consideration. In this respect, progression in learning might be conceptualized as a dynamic and ongoing process involving additions, developments and changes to existing modes of thinking. Progression might be prompted by schooling or through more informal situations. In some instances children will integrate the science concepts learned in school with existing knowledge structures. In other cases, science knowledge will build on existing structures but will tend to be held separately from everyday ways of knowing and will be drawn on as particular contexts demand. It is these developing, multiple ways of knowing which are probed in studies such as the one reported here. In designing the research methodology, the possible knowledge systems used by young people and the way that different research methods may elicit different types of understanding need to be taken into account.

Approaches to probing students' thinking

A wide range of methods for probing students' thinking in science has been developed in recent years (White and Gunstone 1992). Different methods are designed to access different aspects of students' reasoning.

Driver and Erickson (1983) have made the distinction between phenomenological and conceptually based approaches. Phenomenological approaches to probing students' thinking involve presenting students with events or systems and asking students to make predictions and give explanations for the way things happen. No restraint is placed on the way the student responds as he or she talks about the phenomenon using conceptual categories of his or her own choice. The Piagetian clinical interview is the classical example of such an approach. Other phenomenologically framed methodologies have been devised including 'interview-about-events' (Osborne and Gilbert 1980) and 'predict–observe–explain' techniques (Gunstone and White 1981). In all such approaches, it is the student's knowledge scheme relating to the phenomenon in question which is of interest. Moreover it is the student who selects the language and representations to communicate that knowledge scheme.

Conceptually based approaches to probing students' thinking focus on aspects of the students' propositional knowledge structure. Typically, words or propositions are presented and students are asked to perform specific tasks with them. Such approaches include word association techniques (Shavelson 1974), concept mapping (Novak and Gowin 1984), and defining the meaning of terms. Adeniyi (1985), for example, asked Nigerian students to define terms such as 'ecosystem', 'population', 'food chain', 'pyramid of numbers' and noted any differences between student and science definitions. Although this approach allows inferences to be made about the meaning that individuals ascribe to the language and ideas of science, it is not possible to make inferences about the way in which they construe phenomena in their own terms. For example, it is not a logical conclusion that a 13-year-old student from a Nigerian farming community, who cannot remember the meaning of the term 'ecosystem', has no ideas about the relationships between organisms.

The present study aims to document students' own reasoning about ecological phenomena without framing the terms in which responses are given. Hence a phenomenological approach has been used to probe students' thinking by presenting

them with specific biological situations, illustrated through pictures, photographs and video.

Although the terms in which explanations are sought are not constrained explicitly, it is recognized that the social setting of interviews held in a school environment may influence the way students frame responses.

Conceptual analysis to define the study domain

Scientific explanations of the relationships between organisms in ecosystems are complex and draw on a number of key science concepts. In order to define the domain of the present study and to select appropriate phenomena for the probes, the specific science concepts and relationships of interest were first specified.

In broad terms, scientific explanations of organisms in ecosystems involve describing the needs of all organisms for matter and energy, and the mechanisms by which they get this matter and energy. Knowledge of the processes of photosynthesis, respiration, decay, competition and predation is applied to systems of living organisms and non-living entities in the environment to explain the relationship between organisms. In addition, other features such as the need for shelter result in interdependency between organisms.

Six features of the relationship between organisms in ecosystems were identified. These were termed 'Key Ideas', and are summarized as follows:

- *Transfer of matter and energy between organisms*: The need of consumers for matter and energy from producers. The flow of organic matter in ecosystems, as summarized in food chains and webs. The interdependence of organisms in a food web and its importance to the stability of an ecosystem.
- *Exchange of matter and energy with the environment*: The need of organisms to exchange matter and energy with the environment in the form of gases, water, minerals and food. Energy exchanges with the environment, involving light and heat energy.
- *Habitat*: The relationship between the organism and its habitat including structure/function relationships.
- *Photosynthesis*: The process by which producers synthesize food materials using the sun's energy and matter from the environment. The importance of this energy conversion to the biosphere.
- *Respiration*: The process by which all organisms make energy in food available for use, and the associated dissipation of energy to the environment in the form of heat.
- *Decay*: The process of decay and its role in the cycling of organic and inorganic matter. The associated flow of energy to decomposers.

There are obviously relationships between the key ideas. For example, a scientific understanding of transfer of matter and energy between organisms and exchange of matter and energy with the environment requires an understanding of the processes of photosynthesis, respiration and decay. In addition, the *context* in which phenomena are encountered is likely to affect the type of explanation given. For example, a biologist studying the ecology of a woodland habitat may focus on the *flow* of energy between organisms, whereas a biologist studying the ecology of one

Table 1. Mapping of probes on to key ideas.

	Probes				
Key idea	*Apple*	*Video*	*Community*	*Scene*	*Eat*
Photosynthesis			•	•	•
Respiration			•	•	•
Decay	•	•			
Habitat			•	•	
Transfer of matter and energy between organisms			•	•	•
Exchange of matter and energy with the environment	•	•	•	•	•

woodland species may focus on the *source* of energy for that species in a more restricted way.

The research probes

Rationale for the design of the research probes

Five diagnostic instruments or probes were designed to provide contexts through which children's thinking about each of the six key ideas could be investigated. (These probes, called 'Apple', 'Video', 'Community', 'Scene' and 'Eat' are described later in this paper).

Biological situations were selected as contexts for the research probes in such a way as to provide coverage of all the key ideas. Individual probes provide opportunities to use more than one key idea and the overall pattern of coverage is summarized in table 1.

Providing a context for the use of each key idea in more than one probe enabled some investigation of the extent to which children use different ideas in explaining what the scientist sees as being phenomena requiring a similar explanation (Engel Clough and Driver 1986).

As discussed earlier the probes were framed in phenomenological terms, focusing observation and discussion on actual objects or events (such as a rotten apple) or on pictures of natural situations (such as photographs of woodland). Contexts were selected so as to be accessible to children right across the 5–16 age range in terms of both the content of the probes and the mode of presentation. All probes with the exceptions of 'Video' and 'Community' were used with all ages. The probes were administered by interviews up to the age of eight years and through a combination of interviews and paper-and-pencil tasks from age eight upwards. The paper-and-pencil format provided the means to increase significantly the sample size in the older age groups. The validity of the written responses was investigated by comparing individual pupils' responses on interviews and paper-and-pencil tasks using the same probe.

The development of the research probes

All phases of the study, including the development of the probes, were carried out in association with a group of practising primary and secondary teachers. The

development of probes involved a number of stages and is illustrated by considering one probe, 'Apple', in detail.

'Apple' was designed to probe children's ideas about cycling of matter in ecosystems and the role of decay in that process. Working with teachers, various examples of decay familiar to pupils in the 5–16 age range were identified. These included decaying leaf litter, wood and fruit. Photographs and artefacts for each of these examples were collected and presented to small samples of pupils across the age range, in order to determine which of these contexts were familiar to pupils. They were asked whether they had seen anything like these things before, and to describe what they noticed. From this piloting it was decided that decaying fruit was more familiar to pupils than other examples, and this context was used for the development of the 'Apple' probe.

In the probe, pupils were presented with a photograph of a decaying apple lying under an apple tree. The photograph was enlarged to show detail of the apple to pupils, and younger pupils were also shown an actual decaying apple. Pupils were first asked to describe what they noticed about the apple and then to describe what they thought was making this happen. In this way, inferences could be made about the significant features of the phenomenon in the pupil's terms, and the concepts drawn on by pupils to frame their descriptions and explanations.

During pilot studies, many pupils suggested that the apple would get smaller, and so a question was written into the probe to explore where pupils thought the 'stuff' from the apple might go.

In addition, many pupils used words with fairly specific scientific meanings such as 'germs', 'bacteria', 'rot', 'decay' and 'biodegrade'. Whenever these words were raised by pupils in the interviews, they were asked to explain to the interviewer what they meant. An outline interview schedule was devised, drawing both on the outcomes of the pilot trials and the conceptual analysis of the domain. Thus in the 'Apple' probe, some questions related to the nature and cause of decay and others to the fate of matter during the decaying process.

A similar process of piloting was undertaken with the other probes, identifying familiar contexts and using pupils' responses to identify common ways of reasoning. This information was used in designing interview protocols to probe commonly noted forms of reasoning in a systematic way.

In certain parts of the probes it was decided to use questions framed in scientific terms in order to find out whether pupils used different ideas when triggered by 'school science' language. These questions were always placed at the end of interviews, so as not to influence the ideas drawn on by pupils in phenomenologically framed questions. Thus the final question on the 'Apple' probe presented pupils with a brief description of a germ theory of decay, and asked whether they had heard of ideas like this before. If they answered that they had, they were asked to tell the interviewer anything they knew about this.

The content validity of the probes was discussed with an ecologist, whose comments were incorporated into the design.

Probes relating to children's understanding of matter cycling

Two probes, 'Apple' and 'Video', were designed to elicit children's ideas about the process of decay, by presenting pupils with a pictorial or video example of decay,

followed by questioning that allowed pupils to describe in their own terms what they noticed about the process.

Apple probe

The Apple probe was used with pupils from age 5–16 as an interview task, and with pupils from age 8–16 as a pencil-and-paper task.

Pupils were presented with a colour photograph of an apple tree as previously described. The questions asked are listed in Appendix 1 and focus on the appearance of the apple, possible explanations for any differences noted between the apple illustrated and 'normal' apples, and the fate of matter as the apple gets smaller (if this was mentioned).

Once these questions were completed (and collected up in the case of pencil-and-paper tasks), pupils were asked whether they had heard of a germ theory of decay, and to say or write down what they knew.

Video probe

This probe was administered to pupils from age 10–15 as a pencil-and-paper task.

The focus material was a sequence of time-lapse video photography of a bowl of fruit decaying over a period of months. Children were shown the sequence after some explanation of the process of time-lapse photography. They were then shown the video a second time at a slower speed, after which the children were given their response sheets, and the questions were read through. The video sequence was then shown for a final time at the slower speed.

The questions asked pupils for explanations of the changes in the fruit, the time scale of the process and the fate of the fruit matter as the fruit gets smaller. Pupils were also asked to make predictions about possible further changes to the fruit.

Probes relating to children's ideas about the interdependence of organisms in ecosystems

Three probes, 'Community', 'Scene' and 'Eat', were designed to elicit children's ideas about the interdependency of organisms in ecosystems.

Community probe

The community probe was used as a pencil-and-paper task with children from age 8–16. Pupils were presented with a large colour version of the illustration shown in Appendix 1 (figure 1). They were first asked to select a group of six different organisms from those illustrated, using the criterion that they would be able to live together for a long period of time, getting everything they needed. The illustrated environment contained water and light in addition to the organisms selected by the pupils. Having selected a community of organisms, pupils were asked for each organism 'What does it need' and 'Where does it get them from?' Finally, they were asked to consider the six organisms they had chosen and were asked 'which do you think there might be most of?'. The words 'organism', 'animal' and 'plant' were avoided in the wording of the probe as pupils' meanings for these terms may differ from scientific meanings.

Scene probe

The scene probe was administered to pupils from age 5–16 as an interview only. Pupils were presented with a large colour photograph of a woodland scene, including a river and some grassland, and were given picture cards of 40 organisms. They were asked to select from the illustrated organisms those most likely to be found in different places in the picture including the canopy of a tree, in the river and on the grassy bank of the river. In each location pupils were encouraged to choose as many organisms as they thought appropriate. Having identified a group of organisms for a specific location, the interviewer then selected a primary consumer, a secondary consumer and a producer and pupils were asked about the needs of each organism and how those needs were met. They were also asked which organism would be most numerous and to explain their choice.

Eat probe

The Eat probe was administered to pupils from age 8–16 as a pencil-and-paper task, and to pupils from age 5–16 as an interview. Pupils were presented with a line drawing of a large region including fields, mountains and woodland (see Appendix 1, figure 2). Pupils were told that the picture showed a place where plants and animals live together and get everything they need. Each organism in the picture was named. Attention was drawn to the food web for the community and some examples of using the food web were provided (e.g., where do mountain lions get their energy from?).

Pupils were then asked to predict the effects of changing the population of various species at different trophic levels in the food web. They were told that the population size of a primary consumer population was greater than that of a secondary consumer population that preyed on it, and were asked to explain the reason for this. Finally, they were asked about the sources of *matter* for growth of the plants and animals in the community.

The interpretation of arrows in food web diagrams has been found to be difficult for pupils (Schollum 1983). The purpose of the probe was not, however, to find out whether pupils can interpret food web diagrams, but rather to find out what reasoning is drawn on in thinking about populations of organisms. In administering this probe, help was given to pupils to ensure that they understood the feeding relationships represented in the food web. For the interviews with children aged 5–7 the food web diagram was considered to be inappropriate. Instead, the interviewer asked the child where they thought each organism might get energy from and then drew lines on the picture itself to represent this.

Administration of the probes and sampling

Two probes, 'Apple' and 'Eat', were administered as individual interviews and in paper-and-pencil formats. 'Scene' was administered only in interview format and 'Video' and 'Community' only in paper-and-pencil format. In the interviews, which were used with pupils aged 5–16, pupils were told that the purpose of the interview was to find out what they thought about an aspect of science which related to living things living together. The interviewer stressed at the beginning of the interview that he was interested in the subject's ideas, rather than in finding out what the 'right

Table 2. Details of sample.

	Sample size	
Age	For interview sample	For pencil and paper sample
5–7	45	0
7–11	16	81
11–14	16	220
14–16	8	153

Table 3. Details of sample for each probe.

	Probe				
Age	*Apple*	*Video*	*Community*	*Scene*	*Eat*
5–7	(30)	0	0	(30)	(14)
7–11	61 (16)	29	51	(16)	76 (16)
11–14	107 (16)	107	114	(16)	76 (16)
14–16	124 (16)	84	123	(8)	32 (8)

Numbers in parentheses indicate the number of interviews carried out; other numbers indicate pencil-and-paper administration.

answers' were. All interviews were audiotaped for subsequent analysis, and subjects were told that these data would be treated anonymously.

Additional data were collected from children aged 8–16 in written form, using some of the probes. A researcher was present in the classroom to introduce the task to pupils in most cases. Where a researcher was not available to introduce the task, the normal class teacher was given training in the administration of the probes. Silence was not requested while subjects completed the probes, and in practice the atmosphere tended to be one of diligent hard work with some quiet exchanges between pupils rather than silent, examination-like conditions. The probes were read aloud for pupils, and pupils were encouraged to ask for help where they did not know what to do. Many pupils asked for help in *answering* the questions and the researcher and trained teachers dealt with these questions by asking pupils what *they* thought was the answer, and then encouraging them to write down their answer on the sheet.

Subjects were selected from four primary schools and four secondary schools, located in low- to middle-income areas near a large urban area in the north of England. The schools were identified as being typical of schools in the area and sampling of pupils within schools involved taking whole classes as far as was possible. Overall sample sizes and details of samples for each probe are shown in tables 2 and 3.

Analysis of the data

The data from the study comprised audiotaped interviews and pupils' written responses to the probes. The first stage of analysis involved the development of a coding scheme for each of the probes. This was achieved by reviewing pupils'

responses at each age and identifying common ideas and modes of explanation. The coding schemes were thus developed from children's responses rather than being based, for example, on the normative science perspective. For each probe a multiple-feature coding grid was devised to reflect the specific features in the responses, and this resulted in a string of codes for each student response.

Interviews and written responses were coded directly onto spreadsheets, probe by probe, by one researcher. A sample of the data was independently coded by the principal coder and another researcher, and an inter-rater reliability of above 90% was achieved. Pupil responses to questions in each area were considered, and commonly occurring patterns of response were identified. In some cases it appeared that similar views underpinned a variety of responses from different pupils. For example, many pupils explained the decay of the apple with ideas such as the apple had 'died', it no longer received nourishment from the tree, or that it had got 'too old'. These ideas all seemed to involve a view of decay as a 'natural feature of apples' that required no further explanation. Such responses were therefore selected from the spreadsheets and reported together under a 'natural feature' category. In this way broader reporting categories were generated from the initial codings.

The reliability of the probes was determined by comparison of interview and paper-and-pencil responses of individual pupils on the same probe between the ages of seven and 16 (see table 3). In practice there was virtually no difference between the codes of students' responses to interview questions and written questions.

The data were examined for age-related patterns in types of explanation and the final stage of analysis involved a comparison of patterns of responses across different research probes.

Final comments

It is perhaps worth clarifying the claims which can and cannot be made about the findings of a study such as this. The first point to emphasize is that the study is of a cross-sectional design and as such it allows for the reporting of the frequencies with which different ideas and modes of explanation are used by children, in response to particular tasks, at different ages. The study cannot, however, provide details of how individual children's thinking progresses with time. To achieve this, a longitudinal design would be needed.

Furthermore, on the basis of studies such as this, any comment on the nature of progression and what drives it is pure speculation. Nevertheless, careful documentation of children's explanations can contribute to the ongoing debate about the nature of progression in learning by providing empirical evidence against which theories can be evaluated (Carey 1985). Information about the way children at different ages think about natural phenomena can be drawn on in curriculum design, so that teaching is planned to take account of children's current ways of thinking. It is hoped that the findings from this study as reported in the forthcoming papers relating to children's ideas about the cycling of matter and of interdependency will serve such functions.

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References

ADENIYI, E. O. (1985). Misconceptions of selected ecological concepts held by some Nigerian students. *Journal of Biological Education, 19*, 311–316.

BAXTER, J. (1989). Children's understanding of familiar astronomical events. *International Journal of Science Education, 11*, 502–513.

BROOK, A., DRIVER, R. with HIND, D. (1989). *Progression in Science: The Development of Pupils' Understanding of Physical Characteristics of Air across the Age Range 5–16 Years.* Leeds, Centre for Studies in Science and Mathematics Education, University of Leeds.

CAREY, S. (1985). *Conceptual Change in Childhood.* Cambridge, MA: MIT Press.

DRIVER, R. and ERICKSON, G. (1983). Theories-in-action: some theoretical and empirical issues in the study of students' conceptual frameworks in science. *Studies in Science Education, 10*, 37–60.

ENGEL CLOUGH, E. and DRIVER, R. (1986). A study of consistency in the use of students' conceptual frameworks across different task contexts. *Science Education, 70* (4), 473–496.

GUNSTONE, R. F. and WHITE, R. T. (1981). Understanding of gravity. *Science Education, 65*, 291–299.

HOLDING, B. (1987). *Investigation of Schoolchildren's Understanding of the Process of Dissolving with Special Reference to the Conservation of Matter and the Development of Atomistic Ideas.* Leeds, School of Education, University of Leeds.

LEACH, J., DRIVER, R., SCOTT, P. and WOOD-ROBINSON, C. (in press a). Children's ideas about ecology 2: ideas found in children aged 5–16 about the cycling of matter. *International Journal of Science Education.*

LEACH, J., DRIVER, R., SCOTT, P. and WOOD-ROBINSON, C. (in press b). Children's ideas about ecology 3: ideas found in children aged 5–16 about the interdependency of organisms. *International Journal of Science Education.*

NOVAK, J. D. and GOWIN, D. B. (1984). *Learning how to Learn.* Cambridge, Cambridge University Press.

OSBORNE, R. and GILBERT, J. (1980). A method for the investigation of concept understanding in science. *European Journal of Science Education, 2* (3), 311–321.

SCHOLLUM, B. W. (1983). Arrows in science diagrams: help or hindrance for pupils? *Research in Science Education, 13*, 45–49.

SHAVELSON, R. J. (1974). Methods for examining representations of a subject-matter structure in a student's memory. *Journal of Research in Science Teaching, 11*, 231–249.

SOLOMON, J. (1987). Social influences on the construction of pupils' understanding of science. *Studies in Science Education, 14*, 63–82.

WHITE, R. T. and GUNSTONE, R. F. (1992). *Probing Understanding.* London, Falmer Press.

WOOD-ROBINSON, C. (1991). Young people's ideas about plants. *Studies in Science Education, 19*, 119–135.

Appendix 1. Questions used in the 'Apple' probe

- What do you notice about the apple?
- What do you think is making this happen? Write down what you think!
- Do you think that anything might happen to the other apples, left on the ground? Write down what you think!
- If nobody touches these apples after a whole year, what might happen? Write down what you think! Where might the 'stuff' that the apples is made of go to?

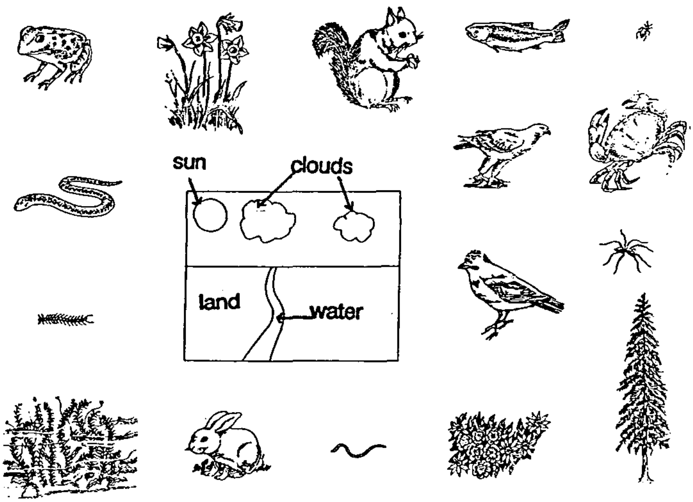

Figure 1. Diagram used in the 'Community' probe.

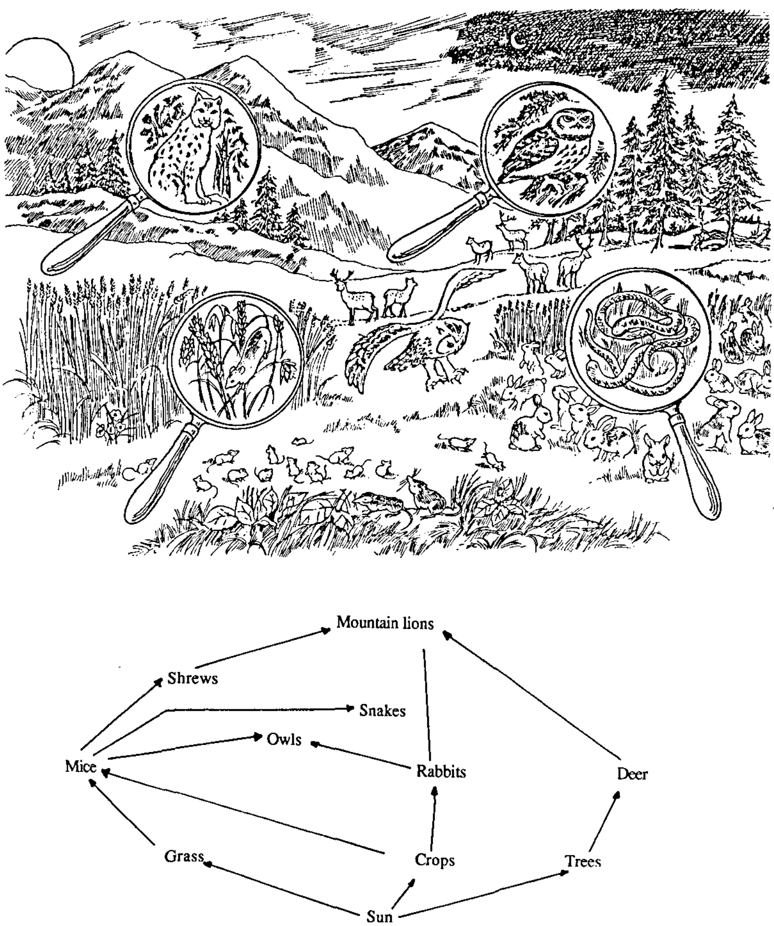

Figure 2. Diagrams used in the 'Eat' probe.